Ann. For. Sci. 63 (2006) 519–523

DOI: 10.1051/forest:2006034


**Original article**

# Comparison of ecosystem C pools in three forests in Spain and Latin America

Felipe GARCÍA-OLIVA[a]*, Guillermina HERNÁNDEZ[b], Juan F. GALLARDO LANCHO[c]

[a] Centro de Investigaciones en Ecosistemas, UNAM, AP 27-3, Sta. María de Guido, Morelia 58090, Michoacán, Mexico
[b] Instituto de Ecología y Sistemática, AP 8029, La Habana 10800, Cuba
[c] Consejo Superior de Investigaciones Científicas, IRNA, Aptado. 257, Salamanca 37071, Spain

(Received 25 April 2005; accepted 23 February 2006)

**Abstract –** To face the lack of information of C content in the main forest ecosystems pools from Spain and Latin America, this study compares C pools of three forest ecosystems: a tropical deciduous forest in Mexico, a tropical wet forest in Cuba and a temperate forest in Spain. The Cuban tropical wet forest had the highest total ecosystem C content (190 Mg C $ha^{-1}$), of which 62% was in the aboveground biomass; followed by the Spanish temperate forest (150 Mg C $ha^{-1}$) with around 75% of total C content was within soil. The Mexican tropical deciduous forest had the lowest total ecosystem C content (82.6 Mg C $ha^{-1}$), of which 51% was in the soil. Tropical forests can not guaranteed sequestered C if the forest programs do not consider aboveground biomass protection. In contrast, temperate forests with slower C sequestration rate by means of soil stabilization are less vulnerable to forest programs.

**biomass / Cuba / Mexico / soil organic C / Spain**

**Résumé – Comparaison du pool de C dans trois écosystèmes forestiers d'Espagne et d'Amérique latine.** Ce travail fait une comparaison entre les teneurs du C des sols appartenant à trois forêts : une forêt caducifoliée tropicale au Mexique, une forêt tropicale à Cuba, et une troisième forêt tempérée en Espagne. La forêt tropicale mexicaine a la plus basse teneur en C (82.6 Mg C $ha^{-1}$) dans l'écosystème, 51 % dans le sol ; la forêt tropicale cubaine a la plus haute teneur en C (190 Mg C $ha^{-1}$) dans l'écosystème, 63 % concentré dans la biomasse ; la forêt espagnole a 150 Mg C $ha^{-1}$ dans l'écosystème, 75 % dans le sol. Les forêts tropicales ne peuvent pas garantir la permanence de la capture du C si l'aménagement de la forêt n'a pas pris en compte la protection de la biomasse aérienne ; par contre, les forêts tempérées, avec un faible taux annuel d'immobilisation du C par le sol, sont moins sensibles à l'aménagement des forêts, puisque la plus grande partie du C est concentrée dans le sol.

**biomasse / C des sols / Cuba / Mexique / Espagne**

## 1. INTRODUCTION

After the Tokyo Protocol [44], the reduction of greenhouse gas emissions to the atmosphere became a priority in the majority of the countries. In this Protocol, forestry activities need to be included for crediting these emissions reductions (under Article 3.3); among these activities reforestation and protection of forested areas can be relevant [46].

On average, soils are the largest carbon pools in global terrestrial ecosystems, because they can contain three times more C than that contained in vegetation [35, 41]. The global soil C pool has been estimated at 1.58 Eg [3, 8], and about 32% (496 Pg) is in tropical soils [26]. Although, soil has been recognized as an important C pool, its capacity for C sequestration is not clear. For example, soil organic carbon (SOC) can increase or decrease after forest to pasture conversion, while under agriculture it was reduced from 30 to 50% [17, 34]. However, the majority of these studies focused on soil C contents and did not include other ecosystems elements related with the dynamic of C fluxes, such as the C inputs to the soil (as above- and belowground productivity). For this reason, soil must be studied as a part of the whole ecosystem to establish its role and the potential for C sequestration [16].

Unfortunately at global scale, there are few studies that have measure C contents in the main pools of ecosystems, being a general rule relating forest from Spain and Latin America. The lack of this information in some regions constrains the understanding of global C dynamics. To help address this lack of information, the present study compares C contents in the main ecosystem pools of three very different forest ecosystems from Spain and Latin America.

## 2. MATERIALS AND METHODS

### 2.1. Selected forest sites

The three selected forests are: (a) a tropical deciduous forest at Chamela, Pacific Coast, Western Mexico; (b) a tropical humid forest at Vallecito, Sierra del Rosario, Western Cuba; and (c) a temperate forest at Navasfrías, Sierra de Gata mountains, Western Spain. The C pools are well documented at these three sites.

* Corresponding author: fgarcia@oikos.unam.mx

Table I shows the location and the main characteristics of the three selected sites. The climate of Chamela (CM) is tropical with a seasonal rainfall pattern with wet summer months (June to October) [14]. The forest is tropical deciduous, dominated by Leguminosae, Euphorbiaceae, and Bignoniaceae plant families [27]. Soils are lithosols, poorly developed with a neutral pH [13].

The climate of Vallecito (VC) is wet tropical with two dry months (between February and April). This forest is tropical evergreen, and Pseudolmedia spuria and Matayba apetala dominate the plant community [4]. Soils are mollic cambisols, shallow with a slightly acid pH [20].

The climate of Navasfrías (NE) is temperate, subhumid Mediterranean with dry summers (June to September) [37]. The forest is a deciduous oak, dominated by Quercus pyrenaica Willd [10]. Soils are orthic umbrisols and the pH is around 5.0 [28].

### 2.2. Methods

Most of the data have been previously published elsewhere, but they have never been compared [11, 15, 20, 21, 24, 31, 33, 39]. Briefly, the methods in each site were described below. In CM, all the measures were done at a mature forest [29]. The aboveground biomass was estimated by Jaramillo et al. [24] using allometric equations developed at Chamela by Martínez-Yrízar et al. [29] based on diameter and high. For this propose, these authors measured diameter and tree high of all individual trees with a diameter greater than 3 cm in 16 plots (2 × 50 m). In the same plots, surface litter (organic layer), roots biomass and soil were also collected [24]. Roots and soil samples were collected at two depth layers: 0–10 cm and 10–20 cm, and their C concentrations were determined in automated C analyzer (CM 5012, UIC, Inc). Soil C contents were calculated taking in account the bulk density of each soil layer sampled. Litterfall was collected monthly in litter tramps during several years [15, 30].

In VC, all the measures were also done in mature forest [32]. The aboveground biomass was estimated following the measures on diameter (1.30 m) and height of total individuals tress within three plots (400 $m^2$), during 4 years [33]. In the same plots, surface litter was collected each month during 5 years from 8 sampling plots (0.5 × 0.5 m) [31]. The roots biomass was done collecting all visible roots in four plots from the first 20 cm soil depth; the extreme values were eliminated and expressed as average of the raining and less raining periods of 2 years [21]. The soil sampling was done by 3 composites samples from each horizon of the soil profile. The COS was estimated by the Walkley–Black method [20, 21] and its contents were calculated according to the corresponding bulk density. Litterfall production was collected monthly for 5 consecutive years in five tramps; the material was dried in oven at 80 °C and mass was measured in dry material [31].

In NE, all the measurements were done in an 80 years-old forest [38]. The aboveground biomass was estimated by allometric equations developed for the same study site using a destructive method (five trees for each DBH class) based in the tree diameter [38]. Surface litter and soil were sampled in three different soil profiles, C concentrations in litter and soil were determined by a Carmhograph (Wosthöff) and soil C content was calculated taking in account the bulk density of each horizons [10, 28]. Root samples were taken from a trench (2 $m^2$) at two depth layers: 0–10 cm and 10–20 cm. The litterfall production was measured during three consecutives years, using 30 litter tramps and sampled periodically through the year [28].

To allow comparison of the three sites, we focussed on belowground biomass and SOC of the first 20 cm soil depth, because both variables are mostly concentrated into this depth [5, 13]. The decomposition constant ($k$) was estimated according Olson [36]:

$$k = P/L \tag{1}$$

where, $P$ is the annual litterfall production (Mg $ha^{-1}$ $y^{-1}$) and $L$ is the annual average of surface litter mass (Mg $ha^{-1}$). The inverse of this constant $k$ is the mean residence time (MRT) expressed in years.

## 3. RESULTS

Table II shows C content in the main ecosystems pools (aboveground biomass, root biomass, litter, and soil) of the three selected forest. As expected, VC had three times higher aboveground biomass than the other two forests (CM and NE), but it is surprising that CM and NE had similar aboveground biomass in spite of such contrasting climates and soil conditions (Tab. I). But CM had two times higher litter mass than the other two forests (VC and NE), while these last two forests had similar litter mass (Tab. II).

In the first 20-cm depth of soil, VC had higher root biomass than the other two forests (CM and NE), corresponding with the aboveground biomass differences among the three forests (Tab. II). In contrast, NE had two times and three times higher SOC content than VC and CM, respectively (Tab. II). Paradoxical, the forest with highest SOC content had the lowest aboveground biomass and litterfall production (Tab. III). Finally, VC had the highest total ecosystem C content, followed by NE, and the lowest value was for CM (Tab. II).

## 4. DISCUSSION

Although, it has been reported that the aboveground biomass increased with the age of stand [22], the effect of age in our study can be negligible, because the two tropical forests are mature (at least >150 years) and the age of temperate forest is around 80 years-old. As hypothesis, the IPCC [18] estimates of aboveground biomass for the three types of forest corresponding to our studied sites are 295 Mg $ha^{-1}$ (tropical wet forest), 175 Mg $ha^{-1}$ (temperate broadleaf forest) and 105 Mg $ha^{-1}$ (tropical dry forest) for VC, NE and CM, respectively. In all the cases, our data are lower than IPCC estimates, remarking the importance of specific site data for establish the baseline of C pools.

The differences between the estimates values by IPCC and our data suggest that the forest productivity is affected by different factors. For example, the differences between VC and NE are explained by global patterns of ecosystem productivity (i.e., temperature, amount of precipitation) [1] as expected values estimated by IPCC. But the differences between the two tropical forests (VC and CM), the seasonality of rainfall is an important factor of productivity rather than the total annual rainfall if the soils had low capacity for keep available water through the year, as CM forest [9]. In the same site of CM forest, the live aboveground biomass ranged from 248 to

**Table I.** General characteristics of the three studied forest sites.

| Sites | Chamela, Mexico | Vallecito, Cuba | Navasfrías, Spain |
|---|---|---|---|
| References | [13, 14] | [20, 31, 45] | [10, 38] |
| Coordinates | 19° 105' N, 105° 05' W | 22° 49' N, 82°58' W | 40°2' N, 3°0' W |
| Altitude (m a.s.l.) | 50 | 400 | 960 |
| Air temperature (°C) | 24 | 24 | 11 |
| Precipitation (mm $y^{-1}$) | 741 | 2 014 | 1 580 |
| Vegetation type | Tropical deciduous forest | Tropical evergreen Forest | Temperate deciduous-oak forest |
| Stand Age | Mature forest | Mature forest | 80 years-old |
| Soil type (FAO) | Lithosol | Mollic cambisol | Orthic umbrisol |
| Texture, *Ah* horizon (%) | Sands 60, silts 14, and clays 26 | Sands 44, silts 24, and clays 31 | Sands 22, silts 38, and clays 21 |
| Bulk density, *Ah* horizon (g $cm^{-3}$) | 0.9 | 1.0 | 0.8 |
| pH, *Ah* horizon ($H_2O$) | 6.5–7.0 | 6.0–6.3 | 4.9–5.1 |

**Table II.** Biomass (Mg $ha^{-1}$) and C contents (Mg C $ha^{-1}$) of the main ecosystems pools of the three studied forest sites.

| Sites | Chamela, Mexico | | Vallecito, Cuba | | Navasfrías, Spain | |
|---|---|---|---|---|---|---|
| References | [15, 24] | | [20, 21, 31, 33, 39] | | [10, 38] | |
| Pools | Biomass | C content | Biomass | C content | Biomass | C content |
| Aboveground biomass | 69.7 | 36.2 (44) | 256 | 118 (62) | 64.6 | 33.6 (22) |
| Roots (0–20 cm) | 17.1 | 6.7 (8) | 36.4 | 18.8 (10) | 21.0 | 10.9 (7) |
| Total biomass | 86.8 | 42.9 (52) | 292.4 | 136.8 (72) | 85.6 | 44.5 (29) |
| Litter | 11.1 | 4.5 (5) | 4.7 | 1.9 (1) | 5.3 | 2.4 (2) |
| SOC (0-20 cm) | N. d. | 35.2 (43) | N. d. | 51.4 (27) | N. d. | 103 (69) |
| TOTAL | N. d. | 82.6 (100) | N. d. | 190 (100) | N. d. | 150 (100) |

The values in the parenthesis are the percentage of total C in each pool. N. d.: no data available; SOC: soil organic carbon.

**Table III.** Carbon fluxes of the three studied forest sites.

| Sites | Chamela, Mexico | Vallecito, Cuba | Navasfrías, Spain |
|---|---|---|---|
| References | [15, 30] | [20, 31] | [10, 38] |
| Litterfall production (Mg C $ha^{-1}$ $y^{-1}$) | 2.1 | 3.8 | 1.2 |
| $k$ referred to litter ($year^{-1}$) | 0.45 | 2.0 | 0.49 |
| MRT litter (year) | 2.2 | 0.5 | 2.0 |
| $k$ referred to SOC ($year^{-1}$) | 0.06 | 0.07 | 0.01 |
| MRT SOC (year) | 16.8 | 13.5 | 86 |

MTR: mean residence time.

390 Mg $ha^{-1}$ in floodplain forest (close to streams) [24], because this forest grown in soils with higher availability of water through the year [9]. The value of aboveground biomass of CV is in the range values of floodplain forest at CM site.

In contrast, the similarities of aboveground biomass between CM and NE forests are not expected by their corresponding climate conditions. An alternative hypothesis is that soil nutrient availability constraint productivity of NE forest. Gallardo and González [12] reported a higher aboveground biomass in a deciduous oak forest at Fuenteguinaldo (FE, 98 Mg $ha^{-1}$) than in NE forest (64.6 Mg $ha^{-1}$). The tree species and age of stands of FE are similar to NE forest; but because of a noticeable difference of annual rainfall, FE (drier) had a higher soil pH (5.4) [28] being the available soil P 7 times higher in FE than in NE (44 and 6 mg $kg^{-1}$, respectively) [28]. In contrast, the productivity of CM forest can not seen constrained by soil nutrient availability (i.e., soil pH is close to 7.0 and available soil P is 61 g $kg^{-1}$) [2].

Residual litter mass is explained by the balance between litterfall production (inputs) and litter decomposition rate (output). As an example, the litterfall production in VC is two times higher than that in CM (Tab. III), but its decomposition constant ($k$) is four times higher than in the Mexican one (CM; Tab. III). In contrast, the litterfall production in NE is 50% lower than in VC, but both forests had similar $k$ referred to litter. These results suggest that a proportion of C produced in the aboveground biomass is accumulated as residual litter in both CM and NE forests, while this accumulation is not observed in VC. In this last forest, the majority of SOC should be originated by root biomass decomposition rather than from the aboveground biomass.

Although, annual C fluxes to litter is two times higher in CM than NE; both forest sites having similar litter $k$ values. This similarity between $k$ values could be explained by lower water availability in CM (shallow soil) than in NE (deep soil profile), while the Spanish oak forest has lower air temperature than the Mexican tropical forest. The combination of both factors (temperature and water) constrains litter decomposition processes in these two forest sites. Epron et al. [7] found that the air temperature and soil water together are better predictor for soil respiration, rather than each variable alone.

SOC content in NE is higher than that in both tropical forest ecosystems, explained by: (a) low $k$ value due to the lower air temperature in NE than in both tropical forest sites; (b) NE temperate soil had a finer texture [11] than in CM, which increase soil C stabilization by organo-mineral complexes [6, 19, 42]; and (c) in NE dry season (summer) interrupt the mineralization processes in NE [11, 40].

The Cuban evergreen forest (VC) has the highest total ecosystem C content concentrated in the aboveground biomass (62%), while around 75% of total ecosystem C content is within soil in temperate NE forest. Hughes et al. [23] also reported that the aboveground biomass stored > 60% of total C ecosystem content in tropical evergreen forest in Mexico (considering the top 30 cm soil depth), and the main losses of C after deforestation is associated with aboveground biomass rather with the soil. Similar results are been reported by other authors in different tropical forests [24, 25, 43]. In contrast, Gallardo and González [12] found higher C content in the soil (0–20 cm) than in the aboveground biomass in two Spanish oak forests.

These results suggest that the ecosystem C content in the VC forest is more vulnerable to anthropogenic disturbances (as deforestation, fires, etc.), while it is more protected in NE forest. CM forest shows the intermediate condition, with around 40% of total ecosystem C is in the aboveground biomass. As a consequence, C contents in tropical forests are more exposed to disturbances than temperate forests, although tropical forests have been considered, as a rule, to have a high capacity for C sequestration.

Forests with high C sequestration rate in aboveground biomass production (as tropical forests) can not retain sequestered C considering over the mid- and long term if the forest programs do not consider aboveground biomass protection (as forest protection). In contrast, forests with slower C sequestration rate, mainly by means of soil stabilization (as temperate forest), are less vulnerable to forest programs. These considerations are critical in defining the duration of forest programs for greenhouse gases mitigation projects.

## 5. CONCLUSIONS

The ecosystem C pools are not explained only by climate factors, but they are also affected by other environmental factors, as soil nutrient availability or soil water dynamic. For these reasons, the estimated values of C pools must be taken carefully for evaluation of mitigation projects and it is crucial promote site studies in regions with scarce data.

**Acknowledgements:** The authors acknowledge positively the comments of two anonymous reviewers. F. García-Oliva acknowledges a grant from the Spanish *Ministerio de Educación, Cultura y Deporte*, during his sabbatical year at IRNA-CSIC, Salamanca (Spain); G. Hernández acknowledges the supports by the UNESCO regional Office of Science and Technology at Montevideo, and the UNESCO Regional Office of Cultura at La Habana and by UNAM for the stay at Center of Investigations in Ecosystems, UNAM, Mexico. The authors thank Heberto Ferreira and Maribel Nava-Mendoza for their assistance in processing data.

## REFERENCES


[1] Aber J.D., Melillo J.M., Terrestrial Ecosystem, Saunders Collage Publ., Philadelphia, USA, 1991.

[2] Alvarez-Santiago S.A., Efecto de la perturbación en la interacción micorrízica vesículoarbuscular en un Ecosistema Tropical Estacional, Master Dissertation, UNAM, México City, México, 1992.

[3] Batjes N.H., Total carbon and nitrogen in the soil of the world, Eur. J. Soil Sci. 47 (1996) 151–163.

[4] Capote R.P., Méndez L., García E., Vilmajó D., Ricardo N., Urbino J., Herrera R.A., Flora y Vegetación, in: Herrera R.A., Méndez L., Rodríguez M., García E. (Eds.), Ecología de los bosques Siempreverdes de la Sierra del Rosario, Cuba, Proyecto MAB No. 1, 1974–1987, ROSTLAC, Montevideo, 1988, pp. 110–130.

[5] Castellanos J., Jaramillo V.J., Sanford R.L. Jr., Kauffman J.B., Slash-and burn effects on fine root biomass and productivity in a tropical dry forest ecosystem in Mexico, For. Ecol. Manage. 148 (2001) 41–50.

[6] Dalal R.C., Mayer C., Long-term trends in fertility of soils under continuous cultivation and cereal cropping in Southern Queensland. III. Distribution and kinetics of soil organic matter in particle-size and density fraction, Aust. J. Soil Res. 25 (1987) 83–93.

[7] Epron D., Ngao J., Granier A., Interannual variation of soil respiration in a beech forest ecosystem over six-year study, Ann. For. Sci. 61 (2004) 499–505.

[8] Eswaran H., Van de Berg E., Reich P., Organic carbon in soils of the world, Soil Sci. Soc. Am. J. 57 (1993) 192–194.

[9] Galicia L., López-Blanco J., Zarco-Arista A.E., Filips V., García-Oliva F., The relationship between solar radiation interception and soil water content in a tropical deciduous forest in Mexico, Catena 36 (1999) 153–164.

[10] Gallardo J.F., Biogeochemistry of Mediterranean forest ecosystems. A case study, Soil Biochem. 10 (2000) 423–460.

[11] Gallardo J.F., Rico M., González M.I., Egido J.A., Moreno G., Martín A., Turrión B., Quilchano C., Vicente M.A., Nutrient cycles and balance in deciduous oak (*Quercus pyrenaica* Willd.) coppices following a rainfall gradient at the Central System range (province of Salamanca, western Spain), Ann. Ist. Sper. Selv. 27 (1996) 13–24.

[12] Gallardo J., Gónzalez M.I., Sequestration of carbon in Spanish deciduous oak forests, Adv. GeoEcol. 37 (2004) 341–351.

[13] García-Oliva F., Maass J.M., Efecto de la transformación de la selva a pradera sobre la dinámica de los nutrientes en un ecosistema tropical estacional en México, Bol. Soc. Bot. México 62 (1998) 39–48.

[14] García-Oliva F., Camou A., Maass J.M., El clima de la Región Central de la costa del Pacífico Mexicano, in: Noguera F.A., Vega J.H., García-Aldrete A.N., Quesada M. (Eds.), Historia Natural de Chamela, Instituto de Biología UNAM, México, 2002, pp. 3–10.

[15] García-Oliva F., Sveshtarova B., Oliva M., Seasonal effect on soil organic carbon dynamic in a tropical deciduous forest ecosystem in western Mexico, J. Trop. Ecol. 19 (2003) 179–188.

[16] García-Oliva F., Masera O.R., Assessment and measurements issues related to soil carbon sequestration in land-use, land-use change, and forestry (LULUCF) project under the Kyoto Protocol, Climatic Change 65 (2004) 347–364.

[17] Guo L.B., Gifford R.M., Soil carbon stocks and land use change: A meta-analysis, Global Change Biol. 8 (2002) 345–360.

[18] IPCC, Revised 1996 IPCC Guidelines for national greenhouse gas inventories Vol 3., Houghton J.T., Meira L.G., Lim B., Treanton K., Mamaty I., Bonduki Y., Griggs D.J., Callander B.A. (Eds.), Intergovernmental Panel on Climate Change, Meteorological Office, Bracknell, UK, 1997.

[19] Hassink J., The capacity of soils to preserve organic C and N by their association with clay and silt particles, Plant Soil 191 (1997) 77–87.

[20] Hernández G., Herrera R.A., Propiedades físico-químicas del suelo y distribución de raicillas, in: Herrera R.A., Méndez L., Rodríguez M., García E. (Eds.), Ecología de los bosques Siempreverdes de la Sierra del Rosario, Cuba, Proyecto MAB No. 1, 1974–1987, ROSTLAC, Montevideo, 1988, pp. 509–517.

[21] Hernández G., Rodríguez M.E., Asimilabilidad y estado del carbono del suelo de un bosque de la Sierra del Rosario, Acta Bot. Cubana 190 (2005) 34–40.

[22] Huet S., Forgeard F., Nys C., Above- and belowground distribution of dry matter and carbon biomass of Atlantic beech (*Fagus sylvatica* L.) in a time sequence, Ann. For. Sci. 61 (2004) 683–694.

[23] Hughes R.F., Kauffman J.B., Jaramillo V.J., Ecosystem-scale impacts of deforestation and land use in a humid tropical region of Mexico, Ecol. Appl. 10 (2000) 515–527.

[24] Jaramillo V.J., Kauffman J.B., Rentaría-Rodríguez L., Cummings D.L., Ellingson L.J., Biomass, carbon, and nitrogen pools in Mexican tropical dry forest landscape, Ecosystems 6 (2003) 609–629.

[25] Kauffman J.B., Cummings D.L., Ward D.E., Fire in the Brazilian Amazon. 2. Biomass, nutrient pools and losses in cattle pastures, Oecologia 113 (1998) 415–427.

[26] Lal R., The potential of soils of the tropics to sequester carbon and mitigate the greenhouse effect, Adv. Agron. 76 (2002) 1–30.

[27] Lott E.J., Annotated checklist of the vascular flora of the Chamela Bay region, Jalisco, Mexico, Occ. Papers Cali. Acad. Sci. 148 (1993) 1–60.

[28] Martín A., Gallardo J.F., Santa Regina I., Interaction between litter and soil epidons in forest ecosystems of the "Sierra de Gata" mountains, province of Salamanca, Spain, Arid Soil Res. Rehab. 9 (1995) 299–305.

[29] Martínez-Yrízar A., Sarukhán J., Pérez-Jiménez L.A., Rincón E., Maass J.M., Solís-Magallanes A., Cervantes L., Above-ground phytomass of a tropical deciduous forest on the coast of Jalisco, Mexico, J. Trop. Ecol. 8 (1992) 87–96.

[30] Martínez-Yrízar A., Maass J.M., PérezJiménez L.A., Sarukhán J., Net primary productivity of a tropical deciduous forest ecosystem in western Mexico, J. Trop. Ecol. 12 (1996) 169–175.

[31] Menéndez L., Dinámica de la producción de hojarasca, in: Herrera R.A., Méndez L., Rodríguez M., García E. (Eds.), Ecología de los bosques Siempreverdes de la Sierra del Rosario, Cuba, Proyecto MAB No. 1, 1974–1987, ROSTLAC, Montevideo, 1988, pp. 213–242.

[32] Menéndez L., Capote R.P., González A.V., La Reserva de la Biosfera. Áreas de estudio, in: Herrera R.A., Méndez L., Rodríguez M., García E. (Eds.), Ecología de los bosques Siempreverdes de la Sierra del Rosario, Cuba, Proyecto MAB No. 1, 1974–1987, ROSTLAC, Montevideo, 1988, pp. 33–60.

[33] Menéndez L., García E.E., Herrera R.A., Rodríguez M.E., Bastart J.A., Estructura y productividad del bosque siempreverde medio de La Sierra del Rosario, in: Herrera R.A., Méndez L., Rodríguez M., García E. (Eds.), Ecología de los bosques Siempreverdes de la Sierra del Rosario, Cuba, Proyecto MAB No. 1, 1974–1987, ROSTLAC, Montevideo, 1988, pp. 151–212.

[34] Murty D., Kirschbaum M.F., McMurtrie R.E., McGilvray H., Does conversion of forest to agricultural land change soil carbon and nitrogen? A review of the literature, Glob. Change Biol. 8 (2000) 105–123.

[35] Post W.M., Pastor J., King A.W., Emanuel W.R., Aspects of interaction between vegetation and soil under global change, in: Wisniewski J., Lugo A.E. (Eds.), Natural sinks of $CO_2$, Kluwer Academic Press, Palmas de Mar, Puerto Rico, 1990, pp. 345–363.

[36] Olson J.S., Energy storage and balance of producers and decomposers in ecological systems, Ecology 44 (1963) 322–331.

[37] Quilchano C., Egido J.A., González M.I., Comparative soil study in a Mediterranean ecosystem of *Quercus pyrenaica* Willd., Geomicrobiol. J. 13 (1995) 265–279.

[38] Quilchano C., Haneklaus S., Gallardo J.F., Schnug E., Moreno G., Sulphur balance in a broadleaf, non-polluted, forest ecosystem (central-western Spain), For. Ecol. Manage. 161 (2002) 205–214.

[39] Rodríguez M.E., Ciclo de nutrientes y estrategias para su conservación en el ecosistema, in: Herrera R.A., Méndez L., Rodríguez M., García E. (Eds.), Ecología de los bosques Siempreverdes de la Sierra del Rosario, Cuba, Proyecto MAB No. 1, 1974–1987, ROSTLAC, Montevideo, 1988, pp. 709–731.

[40] Santa Regina I., Rapp M., Martín A., Gallardo J.F., Nutrient release dynamics in decomposing leaf litter in two Mediterranean deciduous oak species, Ann. Sci. For. 54 (1997) 747–760.

[41] Schlesinger W.H., Evidence from chronosequence studies for a low carbon-storage potential in soil, Nature 348 (1990) 232–234.

[42] Tiessen H., Stewart J.W.B., Carbon and nitrogen in the light fraction of a forest soil: vertical distribution and seasonal patterns, Soil Sci. 135 (1983) 79–87.

[43] Trumbore S.E., Davison E.A., Barbosa de Carmargo P., Nepstad D.E., Martinelli L.A., Belowground cycling of carbon in forest and pasture of Eastern Amazonia, Glob. Biogeochem. Cycles 9 (1995) 515–528.

[44] UNFCCC Kyoto Protocol to the United Nations Framework Convention on Climate Change, Document FCCC/CP/1997/7/Add.1. (Http://www.unfocc.de), 1997.

[45] Vilamajó D., Menéndez L., Suárez A., Características climáticas, in: Herrera R.A., Méndez L., Rodríguez M., García E. (Eds.), Ecología de los bosques Siempreverdes de la Sierra del Rosario, Cuba, Proyecto MAB No. 1, 1974–1987, ROSTLAC, Montevideo, 1988, pp. 61–74.

[46] Watson R.T., Noble I.R., Bolin B., Ravindranat N.H., Verardo D.J., Dokken D.J., Land use, land-use change, and forestry, Intergovernmental Panel on Climate Change (IPCC), Cambridge University Press, New York, 2000.